Calibration of Time-Varied Gain Echosounder Receivers

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by

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ABSTRACT

Buerkle, U. 1984. Calibration of time-varied gain echosounder receivers. Can. Tech. Rep. Fish. Aquat. Sci. 1298: iii + 6 p.

A new method developed to accurately calibrate the time-varied gain echosounder receivers is described. Sampling results are compared to the old method of calibration and errors in biomass estimates produced by the old method are presented.

RÉSUMÉ

Buerkle, U. 1984. Calibration of time-varied gain echosounder receivers. Can. Tech. Rep. Fish. Aquat. Sci. 1298: iii + 6 p.

Nous décrivons dans le présent rapport une nouvelle méthode pour calibrer avec précision les récepteurs de sondeurs à écho à gain à variation dans le temps. Nous comparons les résultats d'échantillonnages avec l'ancienne méthode de calibrage et mentionnons des erreurs d'estimations de biomasse produites par cette dernière.

INTRODUCTION

Echo sounders used in fish abundance estimation commonly use time-varied gain (TVG) receivers to compensate for range-dependent sound intensity losses. These losses are described as the geometrical spreading loss where the sound intensity decreases with the inverse square of the distance, i.e. R^{-2}, and the frequency-dependent attenuation where sound intensity decreases exponentially with distance, i.e. $\exp(-\beta R)$ where β is the attenuation coefficient.

In echo sounding the sound travels over range R meters to the target and back again to the receiver so that the resulting intensity is

$$I_R = I_0 \cdot R^{-4} \exp(-2\beta R)$$

where I_0 is the intensity at 1 m from the sound source. This is commonly called the $40\log R + 2\alpha R$ function and applies in echo counting where fish are spaced apart and can be resolved as single targets.

When fish are too closely spaced to be resolved as single targets, a geometric increase in the number of fish insonified partly compensates for the geometric spreading loss. The resulting intensity at range R in this case is

$$I_R = I_0 \cdot R^{-2} \exp(-2\beta R).$$

This is commonly called the $20\log R + 2\alpha R$ function and is applied in echo integration. Time-varied gain receivers increase their gain with time (i.e. range) by the appropriate function to compensate for transmission loss in echo counting or echo integration.

The latest echo sounders (e.g. Simrad EK400) use digital methods to control these TVG functions accurately, within ±0.5 dB, according to manufacturer's specifications. Sounders without digital control (e.g. Simrad EK50) generate less accurate TVG functions and can produce substantial errors in subsequent abundance estimates unless properly calibrated.

The importance of calibrating TVG functions has not been sufficiently stressed in the manuals for acoustic estimation of fish abundance. Forbes and Nakken (1972) do not mention it; Burczynski (1979) presents an equation for a correction factor that requires knowledge of the actual TVG function but does not give a method for obtaining this function.

The following describes the method developed to determine the functional relationship among input level, range, and output level for a digital acoustic data acquisition system. This system consists of an echo sounder, an echo demodulator and a digital echo envelope recorder. It is used in developing acoustic survey methodology.

The importance of accurate calibration is demonstrated by calculating errors in biomass estimates produced by the former calibration method.

MATERIALS AND METHODS

The acoustic system to be calibrated consists of an echo sounder and a digital data acquisition system. The echo sounder is a Simrad EK50 transceiver with a Simrad 11000 Recorder. The data acquisition system consists of: an echo demodulator to detect the echo envelope (i.e. remove the carrier frequency), a microprocessor to convert the analog data to digital and to format and buffer the data, and a digital tape recorder (Pertek model TG840-9-25) for mass data storage. The demodulator was designed and built at the Marine Ecology Laboratory (MEL) at Bedford Institute of Oceanography, Dartmouth, N. S. (BIO); the microprocessor was built for MEL by Metrology Branch at BIO.

Instruments used in calibration are:

- Signal Generator, Wavetek model 136
- Frequency Counter, Hewlett Packard model 5327B
- Attenuator, HP model 350D
- Tone Burst Generator, General Radio model 13968
- Oscilloscope, Tektronics model 7613
- Pulse Generator, Tektronics mainframe 2601 with 1 Rate/Ramp Generator 26G1 and 2 Pulse Generators 26G3

The aim of this calibration is to determine the relationship among input, range and output of the system so that input can be estimated from measured outputs and ranges. This can be done by providing inputs at known levels and measuring outputs at different times for each input level. The times are converted to ranges by a speed of sound in sea water of 1500 m $\sec^{-1}$. Input to the system at the operating frequency of 49.5 kHz is through the test/input connector on the tranceiver. Continuous Wave (CW) signal long enough to cover the depth range, however, overloads the data handling capacity of the digital system. To reduce the amount of data the input is pulsed to form a train of 0.5 ms pulses 5 ms apart. A block diagram of the instrumentation is shown in Fig. 1.

Most components of the acoustic system are available in duplicate. This reduces the risk of downtime due to equipment failure, but it also necessitates calibration of all combinations of the critical components. To facilitate this the two tranceivers, demodulators and A/D converters are each labeled either 1 or 2. The system configuration is then coded as a three digit number of ones or twos (Table 1). Detailed instructions for equipment connection and settings and for data recording are shown in Appendix 1. This procedure produces a digital magnetic tape of calibration measurements organized in eight files, one for each system configuration. Each file contains measurements of output level and range from 10 transmissions in each of 14 input levels. The input levels range from -69 to -95 dBV (0.4 mV to 0.018 mV) in 2 dB steps.

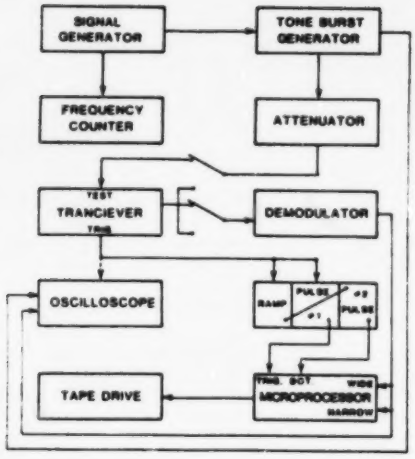

Fig. 1. Block diagram of instrumentations.

Table 1. Acoustic system configuration.

Run	Microprocessor #1	Microprocessor #2	Transceiver #1	Transceiver #2	Demodulator #1	Demodulator #2	Code
1	X		X		X		111
2	X		X			X	112
3	X			X		X	122
4	X			X	X		121
5		X		X	X		221
6		X		X		X	222
7		X	X			X	212
8		X	X		X		211

ANALYSIS

The microprocessor records digital records of echo levels above threshold at 7.5-cm increments in range on magnetic tape. The records are stored in 4000 word buffers together with a time record for each buffer. The words are 16 bit with the bits in each byte reversed and complemented. To facilitate subsequent analysis on the HP3000 system all tapes produced by the acoustic system are translated by a program that restructures the data on new tapes. Output format is binary buffered files with normal HP3000 16-bit words.

The tape produced in calibration is written to the HP compatible form before further processing. The further processing is done by a program written (U. Buerkle) specially to handle the calibration data. The data must be in eight files in proper system configuration order (Table 1) and must be recorded according to the procedures in Appendix 1.

The program determines the relationship of input level, range and output level for each system configuration in order. It fits a least squares multiple regression of the form

$$T_i = a + bS_o + c\text{Log}(R/3) + 2\,d(R-3) \qquad (1)$$

where T_i = tranceiver input (dBv)
S_o = system output (dBv)
R = range (m)

The regression coefficient, c, is the actual compensation in the TVG amplifier for spreading loss. The regression coefficient, d, is the absorption loss actually applied in the TVG amplifier. The range, R, is divided and decreased by 3, respectively, in the two range-dependent terms because the TVG control in the Simrad transceiver becomes active at 3 m (Simrad Pub. P900E). With this equation, input to the system can be calculated for any combination of output and range.

Correcting input for range-dependent transmission losses in later analysis is simply a matter of adding 20 LogR + 2αR (where R is the range and α is the appropriate absorption coefficient) to the transceiver input.

RESULTS

The purpose of this report is to describe the method of calibration rather than to present specific results. To demonstrate the importance of proper calibration, however, two sample results are presented and are compared with results of the former calibration method.

Transceiver input (T_i), system output (S_o) and range (R) in system configuration 112 are related by equation

$$T_i = -32.81 + 0.9649S_o - 20.33\text{Log}(R/3) - 2\text{x}0.0147(R-3) \qquad (2)$$

This shows that the spreading loss correction actually applied (-20.33) is not the required -20, and that the absorption coefficient actually applied (-0.0147) is not the required -0.0122. It also shows that input and output are not linearly related but that input volts (V_i) and output volts (V_o) are related by the power function $V_i = V_o^{0.9649}$. This is contrary to the normal assumption of linearity in the system.

Figure 2 shows measured output levels at range for the first of the 10 transmissions in each input level for 5 of the 14 input levels together with the fitted regression (equation 2). It shows the equation fits the data ($r^2 = 0.999$).

Our former method of calibration, a simple, commonly-used method (Dowd MS 1979; Forbes and Nakken 1972) determines the full gain of the receiver (that is the gain beyond the functional range of TVG control) and assumes the 20LogR + 2αR TVG function. Full gain for system configuration 112 (with input of -69dBv) was measured as 9.99 volts peak (20.0 dBv). The nominal end of TVG

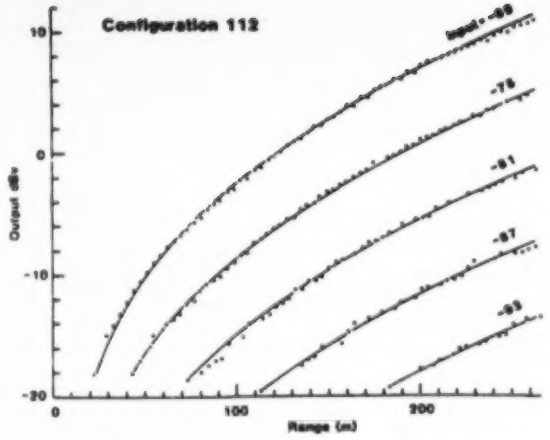

Fig. 2. Measured output levels (points) and fitted regression line for the first transmission at five input levels.

control in the transceiver is 400 m (Simrad Pub. P900E) so that gain at any range G_R can be calculated by

$$G_R = 89.0 - 20\text{Log}(400/R) - 0.0244(400-R) \qquad (3)$$

where R is the range in m, 89.0 is the full gain and 0.0244 is 2α. With known gain at range the input for any combination of output and range can be calculated.

Estimated input at range from the least squares calibration (equation 2) and from the full gain calibration (equation 3) is shown in Fig. 3 for three output levels. It is noted that the estimated input from full gain calibration is consistently lower by several dB than the estimated input from the least squares calibration.

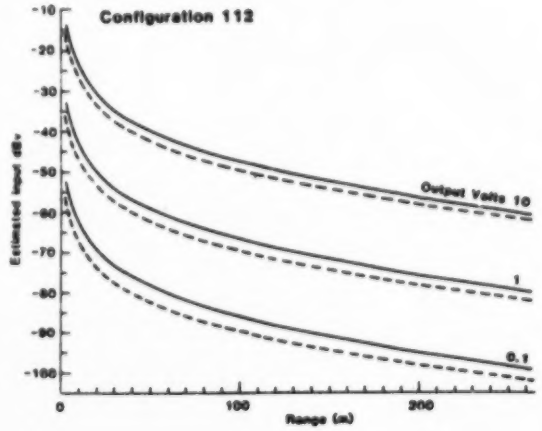

Fig. 3. Estimated input levels for three levels of output with full gain calibration (dashes) and with least squares calibration (line) in system configuration 112.

Such a bias directly affects estimates of acoustic abundance made with this system. The error produced in biomass estimates made using the full gain calibration rather than the least squares calibration is calculated as

$$\%\ \text{error} = 100(10^{(Tif-Tir)/10}-1) \qquad (4)$$

where; Tif = transceiver input with full gain calibration
Tir = transceiver input with least squares calibration.

Figure 4 shows that in the depth range and at the echo levels normally encountered in surveys the biomass is underestimated by 40 to 60% by using full gain calibration. This is a serious bias that cannot be ignored.

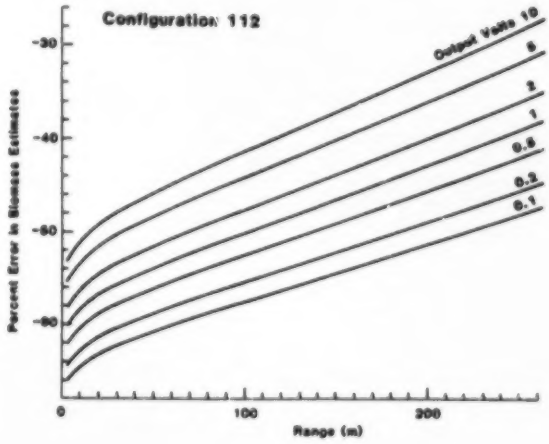

Fig. 4. Percent error produced in acoustic biomass estimates by using full gain calibration rather than least squares calibration in system configuration 112.

To demonstrate that biases are not a unique occurrence in a single system, perhaps introduced by a single system component, the results for configuration 221 are also presented.

The least squares equation for configuration 221 is

$$T_l = -34.22 + 0.9583S_0 - 21.58\text{Log}(R/3) - 2x0.0123.2(R/3) \qquad (5)$$

with $r^2 = 0.999$.

The full gain equation is

$$G_R = 88.6 - 20\text{Log}(400/R) - 0.0244(400-R). \qquad (6)$$

Estimated inputs from the two methods are shown in Fig. 5. It shows that estimated input with full gain calibration can be higher or lower than estimated input with the least squares calibration.

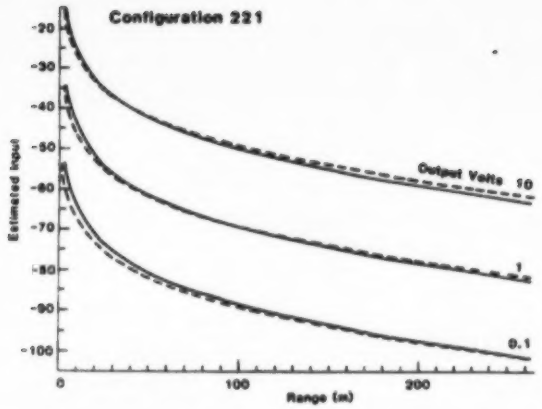

Fig. 5. Estimated input levels for three levels of output with full gain calibration (dashes) and with least squares calibration (line) in system configuration 221.

The errors produced in biomass estimates are shown in Fig. 6, They range from >+40% to <-40% depending on echo level and range. In general, lower level signals at closer range are underestimated and higher level signals at longer range are overestimated.

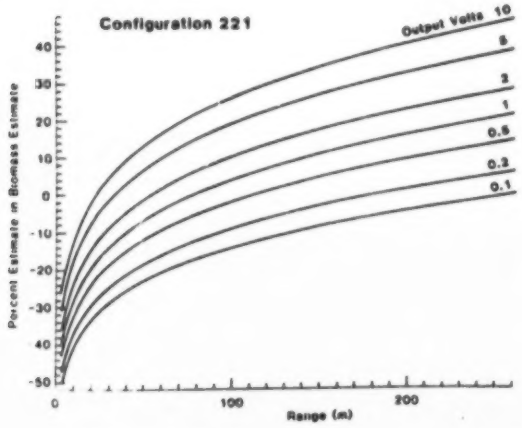

Fig. 6. Percent error produced in acoustic biomass estimates by using full gain calibration rather than least squares calibration in system configuration 221.

The results presented show that calibration of actual system performance is essential for accurate or even reasonable biomass estimation with older acoustic systems. They also suggest that the performance of newer digitally controlled sounders should be verified and monitored at least until reputations become established.

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Forbes, S. T., and O. Nakken. 1972. Manual of methods for fisheries resource survey and appraisal. Part 2. The use of acoustic instruments for fish detection and abundance estimation. FAO, Manual in Fisheries Science No. 5.

Appendix 1: Detailed instructions for generating and recording calibration data.

1. Set up signal generator

   - set frequency to 49.5 kHz (monitor on frequency counter)

2. Set up tune burst generator

   - set to internal trigger
   - set to 0.5 ms ON
   - set to 5 ms OFF
   - adjust DC zero and pedestal null
   - input 49.5 kHz CW from signal generator
   - output pulse train to oscilloscope and attenuator

3. Adjust gain on demodulator

   - set gain at +4 dB (this is done because the maximum output of the transceiver is about 6 volts peak while the microprocessor A/D works to 10 volts peak)

4. Set up system configuration 111

   - set transceiver and recorder to

     - depth range D
     - 20LogR-0dB
     - NORMAL
     - TEST
     - EXT.TRANSMITTER
     - BAND WIDTH 3 KHz

   - connect

     - CAL.OUT to input of demodulator and oscilloscope
     - TRIG.OUT to ramp generator, oscilloscope trigger and pulse generator # 1

   - set ramp generator

     - duration 400 ms
     - output 10 volts ramp to pulse generator # 2

   - set pulse generator # 1

     - trigger on + level-slope
     - duration 0.4 ms
     - amplitude 9.9 volts
     - output to TRIG.IN on microprocessor

   - set pulse generator # 2

     - delay 90% (makes bottom pulse at 265 m)
     - duration 6 ms
     - amplitude 9.9 volts
     - output to BOTTOM on microprocessor

   - connect demodulator output to microprocessor WIDE & NARROW inputs

   - set attenuator to -20 dB

     - adjust gain on signal generator to make attenuator output 0.2 volts peak
     - connect attenuator to transceiver TEST.SIG.input; this loads attenuator output to about 0.1 volt peak

Appendix 1: (cont'd.).

- adjust signal generator to make exactly 0.1 volt peak input to TEST.SIG

5. Start microprocessor run

   - increase attenuation in attenuator by 2 dB every 10 transmissions
   - after 10 transmissions at 46 dB attenuation, wait for tape to advance, then stop microprocessor run

6. Set attenuator to - 20 dB

7. Repeat from step 5 for all 8 system configurations in order on Table 1